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Productivity, efficiency and technical change: measuring the performance of China's transforming agriculture

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Abstract As China enters the twenty-first century the health of the agricultural economy will increasingly rely, not on the growth of inputs, but on the growth of total factor productivity (TFP). However, the tremendous changes in the sector—sometimes back and sometimes forwards—as well as evolving institutions make it difficult to gauge from casual observation if the sector is healthy or not. Research spending has waxed and waned. Policies to encourage the import of foreign technologies have been applied unevenly. Structural adjustment policies also triggered wrenching changes in the sector. Horticulture and livestock production has boomed; while the output of other crops, such as rice, wheat and soybeans, has stagnated or fallen. At a time when China's millions of producers are faced with complex decisions, the extension system is crumbling and farmer professional associations remain in their infancy. In short, there are just as many reasons to be optimistic about the productivity trends in agriculture as to be pessimistic. In this paper, we pursue one overall goal: to better understand the productivity trends in China's agricultural sector during the reform era—with an emphasis on the 1990–2004 period. To do so, we pursue three specific objectives. First, relying on the National Cost of Production Data Set—China's most complete set of farm input and output data—we chart the input and output trends for 23 of China's main farm commodities. Second, using a stochastic production frontier function approach we estimate the rate of change in TFP for each commodity. Finally, we decompose the changes in TFP into two components: changes in efficiency and changes in technical change. Our findings—especially after the early 1990s are remarkably consistent. China's agricultural TFP has grown at a healthy rate for all 23 commodities. TFP growth for the staple commodities generally rose around 2% annually; TFP growth for most horticulture and livestock commodities was even higher (between 3 and 5%). Equally consistent, we find that most of the change is accounted for by technical change. The analysis is consistent with the conclusion that new technologies have pushed out the production functions, since technical change accounts for most of the rise in TFP. In the case of many of the commodities, however, the efficiency of producers—that is, the average distance of producers from the production frontier—has fallen. In other words, China's TFP growth would have been even higher had the efficiency of production not eroded the gains of technical change. Although we do not pinpoint the source of rising inefficiency, the results are consistent with a story that there is considerable disequilibrium in the farm economy during this period of rapid structural change and farmers are getting little help in making these adjustments from the extension system.

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1 Introduction

During the early reform period there are few scholars that question the positive role that agriculture played in the economy and sources of the large rises of food and fiber (Rozelle et al. 2005). Based in part on the incentives embodied in the Household Responsibility System, farm output and productivity grew by 5–10% between 1978 and 1985 (McMillan et al. 1989; Lin 1992). Huang and Rozelle (1996), and Fan and Pardey (1997) show that better incentives were enhanced by new technologies. Inputs also rose as farmers had greater access to fertilizer and other farm inputs (Stone 1988) and improved water control, especially due to the emergence of groundwater (Nickum 1998; Wang et al. 2005).

During the mid-1990s, at a time when China's rapid growth was becoming recognized as a transformative force of people's livelihood, another debate rose about whether China could feed itself. Brown (1994) among others pointed out that the level of input use was already high in China and that future growth would rely on total factor productivity (TFP) growth. The pessimist (e.g., Wen 1993) suggested that TFP had stopped growing and that China's farming sector was unhealthy. In response, several efforts (e.g., Fan 1997; Jin et al. 2002) used more rigorous methods and showed that while aggregated inputs had indeed stopped growing (as labor shifted off the farm; sown area was stagnant), output continued to grow resulting in positive TFP growth, which was at a respectable rate of around 2% per year. Although there were many challenges facing the agricultural economy as China entered the end of the 1990s, it was shown that the investment into R&D (which because of time lags between investment and production of new varieties had taken place in the late 1970s and 1980s) was producing the technology that was driving TFP.

Somewhat surprisingly in recent years there has been almost no work done to continue to monitor the health of China's agricultural economy. According to our reading of the literature, there are no papers that use high quality nationwide input and output to rigorously measure shifts in productivity. In contrast, in other countries there are annual efforts to track changes in productivity.

The lack of information on TFP is all the more surprising since as China enters the twenty-first century the health of the agricultural economy will increasingly rely, not on the growth of inputs, but on the growth of total factor productivity (TFP). There are tremendous changes in the sector—sometimes back and sometimes forwards—as well as evolving institutions which make it difficult to gauge from casual observation if the sector is healthy or not. Research spending has waxed and waned (Hu et al. 2007). Policies to encourage the import of foreign technologies have been applied unevenly (Pray et al. 1997). Structural adjustment policies also triggered wrenching changes in the sector (Rosen et al. 2004). Horticulture and livestock production has boomed; while the output of other crops, such as rice, wheat and soybeans, has stagnated or fallen (CNBS 2005). At a time when China's millions of producers are faced with complex decisions, the extension system is crumbling and farmer professional associations remain in their infancy (Huang et al. 2003). In short, there are just as many reasons to be optimistic about the productivity trends in agriculture as to be pessimistic. Yet, there is no where in the literature to turn to understand the trends in productivity over the past 15 years.

Because of this absence of information, the overall goal of this paper is to better understand the productivity trends in China's agricultural sector during the reform era—with an emphasis on the 1990–2004 period. To do so, we pursue three specific objectives. First, relying on the National Cost of Production Data Set—China's most complete set of farm input and output data—we chart the input and output trends for 23 of China's main farm commodities. Second, using a stochastic production frontier function approach we estimate the rate of change in TFP for each commodity. Finally, we decompose the changes in TFP into two components: changes in efficiency and changes in technical change.

Because this already is an ambitious paper, we necessarily must limit the scope of the analysis. Specifically, we exam the major staple grains and oilseeds, cotton, several vegetable and fruit crops and most of the major livestock commodities. In total, the commodities that are covered accounted for more than 63% of China's gross value of agricultural output in 2005 (CNBS 2006). However, due to the lack of data and time, we do not estimate TFP growth for several major commodities, including aquaculture, sugar, edible oils beyond soybeans and many fruits, vegetables and more minor livestock commodities. In addition, we measure the productivity shifts on a commodity by commodity basis. As shown in deBrauw et al. (2004) and Lin (1992), if the rise of specialization in China is occurring (as is reported in the literature—Rozelle et al. 2007) and this results in the positive allocative efficiency gains, our approach underestimates the total rise in productivity in China's farming sector. We also ignore regional differences in productivity, even though our results are done on a province by province basis and aggregated to a national total.

To meet our objectives the rest of the paper is organized as follows. In the following sections we first present a brief review of our methodology. Next, we discuss the data. The following section contains a brief review of recent changes in China's agriculture and how these might be expected to affect TFP. Understanding these trends will be helpful in interpreting the results. TFP growth rates and their decomposition are then presented for the 23 commodities. The final section concludes.

2 Methodology

Traditional studies of productivity growth in agriculture have tended to compute productivity as a residual after accounting for input growth, and to interpret the growth in productivity as the contribution of technical progress. Such an interpretation implies that improvements in productivity can arise only from technical progress. However, this assumption is valid only if firms are technically efficient, thus operating on their production frontiers and realizing the full potential of the technology. The fact is that for various reasons firms do not operate on their frontiers but somewhere below them, and TFP measured in this way can reflect both technological innovation and changes in efficiency. Therefore, technical progress may not be the only source of total productivity growth, and it will be possible to increase factor productivity through improving the method of application of the given technology—that is, by improving technical efficiency.

To study production efficiency, the stochastic frontier production function (Aigner et al. 1977; Meeusen and van den Broeck 1977) has been the subject of considerable recent research with regard to both extensions and applications (Battese and Coelli 1995). Stochastic production function analysis postulates the existence of technical inefficiency of production of firms involved in producing a particular output, which reflects the fact that many firms do not operate on their frontiers but somewhere below them. Many theoretical and empirical studies on production efficiency/inefficiency have used stochastic frontier production analysis (e.g., Coelli et al. 1998; Kumbhakar and Lovell 2000).

Stochastic frontier production functions have also been applied to the analysis of aggregate production data. This is true when the underlying household data have been aggregated to the state or country level. For example, Kooper et al. (1999) use a stochastic frontier production approach to examine country specific inefficiency of a group of OECD countries. While Kooper (2001) criticized Kooper et al. (1999) and Fare et al. (1994) for the assumption of all these countries facing a common world production frontier for real GDP, he was focusing on the manufacturing sector. He argues that it is more realistic to assume there is a common OECD production function for machinery production than for GDP as a whole.

There are other examples. Using provincial level panel data from China's 30 provinces/cities, Yao et al. (2001) use frontier production function analysis to examine the technical efficiency of China's grain sector. Tian and Wan (2000) carry out a similar analysis, but at individual crop level (i.e. rice, wheat and corn, however, still using aggregate data). In this paper we also adopt stochastic frontier production function for individual commodities.

Recent development of techniques for measuring productive efficiency over time has focused on the use of panel data (Kumbhakar et al. 1999; Henderson 2003). Panel data permit a richer specification of technical change and obviously contain more information about a particular unit of analysis than does a cross-section of the data. Panel data also allow the relaxation of some of the strong assumptions that are related to efficiency measurement in the cross-sectional framework (Schmidt and Sickles 1984). In the rest of the paper, we adopt a panel data approach to measure and decompose TFP for our 23 commodities.

As in Kumbhakar (2000), the stochastic frontier production function for panel data can be expressed as:

$$y_{it} = f(x_{it}, t)\exp(v_{it} - u_{it}) \tag{1}$$

where y_{it} is the output of the ith firm $(i = 1, 2, \ldots, N)$ in period t $(t = 1, 2, \ldots, T)$; $f(\cdot)$ is the production technology; x is a vector of J inputs; t is the time trend variable; v_{it} is assumed to be an iid $N(0, \sigma_v^2)$ random variable, independently distributed of the u_{it}; and u_{it} is a non-negative random variable and output-oriented technical inefficiency term.

In this paper we assume that the production technology is translog:

$$\begin{aligned}\ln y_{it} = \alpha_0 &+ \sum\nolimits_j \beta_j \ln x_{jit} + \beta_t t \\ &+ \frac{1}{2}\sum\nolimits_j \sum\nolimits_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \frac{1}{2}\beta_{tt} t^2 \\ &+ \sum\nolimits_j \beta_{jt} \ln x_{jit} t + v_{it} - u_{it}\end{aligned} \tag{2}$$

A translog is assumed since it is a flexible functional form. In addition, it is well known that a translog is a second order approximation of any production technology, making it a general functional form.[1] In order to account for unobserved, non-time varying factors (or fixed effects), we included a set of provincial dummy variables in the specification. In addition, the time trend variable controls for time varying, systematic unobserved factors.

There are several specifications that make the technical inefficiency term u_{it} time-varying, but most of them have not explicitly formulated a model for these technical inefficiency effects in terms of appropriate explanatory

[1] The translog was chosen not only because it is one of the most popular function forms in the related literature, but also because it performs better than other alternatives based on a formal test.

variables.[2] Battese and Coelli (1995) proposed a specification for the technical inefficiency effect in the stochastic frontier production function as:

$$u_{it} = z_{it}\delta + w_{it} \tag{3}$$

where the random variable w_{it} is defined by the truncation of the normal distribution with zero mean and variance σ^2, such that the point of truncation is $-z_{it}\delta$, i.e., $w_{it} \geq -z_{it}\delta$. As a result, u_{it} is obtained by truncation at zero of the normal distribution with mean $z_{it}\delta$ and variance σ^2. The normal assumption that the $u_{it}s$ and $v_{it}s$ are independently distributed for all $i = 1, 2, \ldots, N$ and $t = 1, 2, \ldots, T$ is obviously a simplifying but restrictive condition. Replacing Z_{it} by t (time trend) and D_i (provincial dummy variable), the technical inefficiency function u_{it} can be defined as:

$$u_{it} = \delta_0 + \delta_1 t + \sum \delta_{2i} D_i + w_i \tag{4}$$

The provincial dummy variables are included to account for unobserved, non-time varying factors (or fixed effects). The time trend variable controls for time varying, systematic unobserved factors.

Since there are serious econometric problems with two-stage formulation estimation (Kumbhakar and Lovell, pp. 264), our study simultaneously estimates the parameters of the stochastic frontier function (2) and the model for the technical inefficiency effects (4). The likelihood function of the model is presented in the appendix of Battese and Coelli (1995). We use the FRONTIER 4.1 computer program developed by Coelli to estimate the stochastic frontier function and technical inefficiency models simultaneously and this program also permits the use of our unbalanced panel data.

Technical inefficiency, u_{it}, measures the proportion by which actual output, y_{it}, falls short of maximum possible output or frontier output $f(x, t)$. Therefore, technical efficiency (TE) can be defined by:

$$\mathrm{TE}_{it} = y_{it}/f(x_{it}, t) = \exp(-u_{it}) \leq 1 \tag{5}$$

Time is included as a regressor in the frontier production function and used to capture trends in productivity change—popularly known as exogenous technical change and is measured by the log derivative of the stochastic frontier production function with respect to time (Kumbhakar 2000). That is, technical change (TC) is defined as:

$$\mathrm{TC}_{it} = \frac{\partial \ln f(x_{it}, t)}{\partial t} \tag{6}$$

Productivity change can be measured by the change in TFP and is defined as:

$$\dot{\mathrm{TFP}}_{it} = \dot{y}_{it} + \sum\nolimits_j S_{jit}\dot{x}_{jit} \tag{7}$$

where S_{jit} is the cost-share of the jth input for the ith firm at time t. Kumbhakar (2000) has shown that the overall productivity change can be decomposed by differentiating Eq. (1) totally and using the definition of TFP change in Eq. (7). This results in a decomposition of the TFP change into four components: a scale effect, pure technical change, technical efficiency change and the input price allocative effect. Since our main interest in the paper was decomposing changes in efficiency into two components—technical change and technical efficiency, we did not report the elements for scale effects and input price allocative effects. In fact, the reason that we did not was because traditionally in Asian cropping systems with small land holdings, scale effects are not very important.

3 Data

Historically estimates of China's cropping TFP have been controversial, arriving at significantly different conclusions. Poor data and ad hoc weights may account for the debates and uncertainty over pre- and post-reform productivity studies. Researchers gleaned data from a variety of sources; they warn readers of the poor quality of many of the input and output series (Stone and Rozelle 1995).

3.1 Data and methodology for creating TFP measures

In this paper, we overcome some of the shortcomings of the earlier literature by taking advantage of data that have been collected for the past 25 years by the State Price Bureau. Using a sampling framework with more than 20,000 households, enumerators collect data on the costs of production of all of China's major crops. The data set contains information on quantities and total expenditures of all major inputs, as well as expenditure on a large number of miscellaneous costs. Each farmer also reports output and the total revenues earned from the crop. Provincial surveys by the same unit supply unit costs for labor that reflect the opportunity cost of the daily wage foregone by farmers that work in cropping. During the last several years, these data have been published by the State Development and Planning Commission ("The Compiled Materials of Costs and Profits of Agricultural Products of China", SPB 1988–2004). The data have previously been used in analyses on China's agricultural supply and input demand (Huang and Rozelle 1996; Huang et al. 1999; World Bank 1997; Jin et al. 2002; Ma et al. 2004a, b; Rae et al. 2006).

In this paper, we attempt to examine the record of TFP for a large cross section of China's most important

[2] See Kumbhakar and Lovell (Chap. 7) for a review of recent approaches to the incorporation of exogenous influences on technical inefficiency.

commodities. Because of this and in order to provide continuity with previous studies that mostly examined grain crops, we also examine rice, wheat and maize. Because the characteristics of major types of rice vary so much across space and over time, we provide separate TFP analyses for early and late Indica varieties (or long grain rice) and for Japonica varieties (short/medium grain rice). We also examine the productivity trends of China's largest non-grain staple crop—soybeans and cotton.

The rise of China as a major horticulture producer (and exporter) and its clear comparative advantage in producing labor intensive farm commodities have made us include four vegetables (capsicum; eggplant, cucumbers and tomatoes) and two fruit crop (mandarin oranges and regular oranges). Lack of data preclude including any more. Because cucumbers and tomatoes are grown in large quantities both in the field and in greenhouses, we examine TFP separately for these two crops.

The increasing importance of livestock commodities in China and the prospect for even greater increases demands that we examine changes in TFP for major livestock commodities. Therefore, the study examines TFP growth for hogs, egg, beef cattle and dairy. Because of the radical differences in the technologies used in China's backyard, specialized household and commercial sectors, in the analysis of TFP in the livestock sector, we examine productivity separately for backyard hog production, production by specialized households (those raising relatively large numbers of hogs) and commercial hog producers (called state and collective-owned farms). We also examine production of eggs for both specialized household and commercial producers. The TFP analysis for beef cattle is focused on aggregate production only since the data on backyard, specialized household and commercial producers are not available. Finally, we examine the changes in TFP of two types of dairy producers—specialized household milk producers and the commercial producers.

Data for the livestock sector was particularly problematic for a number of reasons. Because of this, we had to employ a number of assumptions and external pieces of information to create consistent and empirical sensible data series at the province level. These adjustments are described in detail in "Appendix 1". Adjustments were also needed for dairy. These are described in "Appendix 2" and Ma et al. (2006).

While this is an invaluable data set and matches that needs of the methodology described in the previous section, there are several limitations. First, because of China's grain-first mentality in the 1980s, coverage of non-grain crops is extremely spotty in the 1980s. Because of this we can only produce TFP estimates in the 1980s for rice, wheat, maize, soybeans and cotton. All of the rest of the commodities are reported for 1990–2003 or 2004. Second, because of data availability by province we necessarily had to use unbalanced panel methods. The list of coverage (number of provinces and number of years) for each commodity is in "Appendix 3".

We have to limit our attention to major agricultural commodities. The major agricultural commodities that are included in our study still account for more than 63% of total gross agricultural value (excluding forestry and fishery) during the period of 2000–2005. The share of each commodity in nation's total gross agricultural value from 1980 to 2005 is summarized in "Appendix 4". The difficulties of getting data for other commodities prevent us from including them in the study.

4 Economic forces, structural change and productivity

Three major forces are likely to be affecting the growth of TFP of China's major agricultural commodities: a) investment in R&D through China's domestic agricultural research system and the availability through other channel to new technologies; b) the performance of the agricultural extension system; and c) other economic forces that will push farmers into and out of different agricultural commodities, methods of production (e.g., in the backyard or in commercial lots) and technologies (e.g., greenhouses, etc.). The strength of the various forces (or lack thereof) will determine if productivity has been enhanced or limited by increasing or decreasing efficiency or by increasing or decreasing technical change. The final magnitude of the growth or contraction of total factor productivity is decided by the sum of changes in efficiency and changes in technical change.

4.1 Technology development

After the 1960s, China's research institutions grew rapidly, from almost nothing in the 1950s, to a system that now produces a steady flow of new varieties and other technologies. China's farmers used semi-dwarf varieties several years before the release of Green Revolution technology elsewhere. China was the first country to develop and extend hybrid rice. Chinese-bred conventional rice varieties, wheat, and sweet potatoes were comparable to the best in the world in the pre-reform era (Stone 1988).

Agricultural research and plant breeding in China is almost completely organized by the government (Huang et al. 2003—the book). Reflecting the urban bias of food policy, most crop breeding programs have emphasized fine grains (rice and wheat) until the 1990s. For national food security consideration, high yields have been major target of China's research program except for recent years when the quality improvement was introduced into the nation's development plan. In recent years, however, there has been more effort focused on breeding for horticulture and livestock.

A nationwide reform in research was launched in the mid-1980s (Pray et al. 1997). The reforms attempted to increase research productivity by shifting funding from institutional support to competitive grants, supporting research useful for economic development, and encouraging applied research institutes to support themselves by selling the technology they produce. In addition, in the late 1980s and early 1990s, imports of new horticultural seeds, genetics for improvement of the nation's livestock inventories (Rae et al. 2006) and new technologies for dairy (Ma et al. 2006).

After waning for more than a decade (between the early 1980s and mid-1990s—Pray et al. 1997), investment into R&D finally began to rise. Funding was greatly increased for plant biotechnology, although only Bt cotton has been commercialized in a major way (Huang et al. 2002). Since 1995 investment by the government into R&D increased by 5.5% annually between 1995 and 2000 and by more than 15% annually after 2000 (Hu et al. 2007).

4.2 Extension system

If spending on the agricultural research system is best characterized as a U-shaped curve and is a system that has had a modicum of success in reform, the extension system is best considered a long, downward sloping slide and is characterized by few, if any, major successes. At its peak, the extension system in China was one of the most effective in the developing world. A public funded system, there were extension agents at the county and township level. From above, they were supported by ties in a provincial research system which also had experiment stations in almost every prefecture. From below, communes during the Socialist era and villages after reform appointed one or more representatives from the village to be a liaison between the farmers and the extension system.

After the mid-1980s, however, fiscal pressures at all levels of government induced local officials to try to commercialize the extension system. Although there have been differences over time and across space, in most localities commercialization was attempted by partially privatizing the position of extension agent (Park and Rozelle 1998). In return for working part of their time doing traditional extension activities, extension agents were allowed to go into business, most often selling seeds, fertilizer and pesticides. The profits from their business activities were supposed to cross subsidize their extension activities. At the most extension agents found their salaries reduced by half or more. In many areas, payments were completely stopped and they were expected to continue to do their extension duties while at the same time be a business person.

As might be expected, because of difficulties in monitoring and the incentives to spend most or all of their time on their income earning activities, the extension system went into a period of near disintegration. Surveys found that most farmers rarely, if ever, saw extension agents. In other work, it has been documented that extension agents were overselling pesticides, and providing farmers with inaccurate information when the emergence of new technologies (e.g., Bt cotton seeds) conflicted with their business practices (sales of pesticides—Huang et al. 2003). It has even been documented empirically, that the greater the extension effort, the lower the productivity (Jin et al. 2002). A recent survey of dairy, livestock and horticulture farmers found that there was little if any support for these activities from the formal extension system (which is still staffed with agronomists trained during the grain-first years of China's agricultural policy).

4.3 Other forces

There are other economic forces that should be expected to affect the nation's productivity. First, and above, all since the structural adjustment policies and the acceleration of China's growth in the late 1990s, there has been a veritable tidal wave of change. China's agricultural economy has steadily been remaking itself from a grain-first sector to one producing higher valued cash crops, horticultural goods and livestock/aquaculture products. In the early reform period, output growth—driven by increases in yields—was experienced in all subsectors of agriculture, including grains. For example, between 1978 and 1984, grain production, in general, increased by 4.7% per year. Production rose for each of the major grains—rice, wheat and maize. However, after the mid-1990s, with the exception of maize that is now almost exclusively used for feed, rice and wheat sown area and production have fallen. Although this may concern old-time grain fundamentalist inside China, in fact, the fall in supply of grain has been led by the collapse in demand, as rising incomes in urban and rural areas, migration and marketization has pushed people away from grains into alternative crops.

Like the grain sector, cash crops, in general, and specific crops, such as cotton, edible oils and vegetables and fruit, also grew rapidly in the early reform period when compared to the 1970s. Unlike grain (with the exception of land-intensive staples, such as cotton), the growth of the non-grain sector continued throughout the reform era. Moreover, the rise in some sectors has been so fast that it almost defies description. For example, between 1990 and 2004 the increase in vegetable production capacity has been so fast that China as a nation is adding the equivalent of the production capacity of California (the world's most productive vegetable basket) every 2 years. When compared on the basis of the share of cultivated area dedicated to fruit orchards, the share in China (over 5%) is more than double the share of the next closest major agricultural nation (including the US, the EU, Japan, India). China today can more closely be said to following "taking cucumbers and oranges as the key link" than being a grain-first agriculture as in the Socialist era.

China also is moving rapidly away from a cropping agricultural mentality. The rise of livestock and fishery sectors outpaces the cropping sector, in general, and most of the subcategories of cropping. Livestock production rose 9.1% per year in the early reform period and has continued to grow at between 4.5 and 8.8% per year since 1985. The fisheries subsector is the fastest growing component of agriculture, rising more than 10% per year in 1985–2000. Today, more than 70% of the world's fresh water aquaculture is produced in China. And, the rapid and continuous rise in livestock and fisheries has steadily eroded the predominance of cropping. After remaining fairly static during the Socialist era, the share of agriculture contributed by cropping fell from 76 to 51% between 1980 and 2005. At the same time, the combined share of livestock and fisheries rose to 45%, more than doubling their 1980 share (only 20%). It is projected that by 2008, cropping will account for less than 50% of agricultural output in China. Dairy demand is also rising extremely rapidly (Fuller et al. 2006).

Simultaneous with these changes, China has also experienced an explosion of market-oriented activities (Rozelle et al. 2000). While the policies were gradual, throughout the 1980s and 1990s, the role of the state in China's markets has diminished. In its place there has been a rise of private traders and wholesale markets staffed by private traders that today has given China one of the most efficient sets of markets in the world (Huang et al. 2004). Competitive markets also have been documented for the emerging horticultural sector (Wang et al. 2006). Dairy, livestock and other commodities also are characterized by competitive markets.

4.4 Expected effects on TFP

Exante it is difficult to assess how China's investment into agricultural R&D and other shifts in policies affecting the availability of technology; changes in the extension system and other economic forces have affected total factor productivity. The effect of any one of these forces depends on the direction of the change and its magnitude. Unfortunately, it is difficult to quantify these forces and formally decompose the change in TFP into its component sources. Additional complexity is added because some of the changes will affect efficiency and others will affect technical change.

However, stepping back there are some forces for which we have a fairly good intuitive idea about the direction of the impact. For example, the deterioration of the extension system almost certainly will have had a negative effect on TFP and would mainly affect the efficiency of farming by not teaching farmers how to use the newly available technologies. In contrast, the new regulations for the importation of genetics, horticultural varieties and dairy technology and the rise of markets that make these available to farmers should promote TFP through the rise of technical change.

However, the effect of other forces is more difficult to predict. Will the falling R&D investment in the 1980s and 1990s show up as falling technical change (especially in the case of grains)? Will the continued restrictions on the investment into agricultural R&D for the major grains limit the pace of technical change? At the same time, better incentives through research reform and better scientific inputs should raise TFP through its positive influence on technical change. Hence, for agricultural R&D, in particular, and for the effect of all economic forces, in general, the final word on how the health of the agricultural economy has fared is an empirical one.

5 Inputs, outputs and productivity: before 1995

After the extremely fast growth in output and fall in inputs (mostly labor that shifted to sidelines and other off farm activities) that was documented in early 1980s during the implementation of the Household Responsibility System (McMillan et al. 1989; Lin 1992), leaders became concerned with the pace of the growth of output during the subsequent decade. In fact, our data contain traces of evidence that the concerns were justified in the case of some crops but not others. Figure 1 demonstrates that between 1985 and 1994 the growth rate of output of early and late indica rice, japonica and soybeans fell to below 2% (top panel). The growth of early indica rice was almost zero. While zero growth rates are not always bad from a productivity point of view (since inputs could be falling faster), in the case of these four crops, inputs actually rose faster, at an annual rate ranging from 1.7 to 4.0%. At least for these crops, it is clear why officials were concerned about productivity.

However, in the case of other staple grain crops—wheat and maize—there is less room for concern. Although in no way close to the rates of increase that were enjoyed before 1985, between 1985 and 1994 output for wheat and maize rose, respectively to 2.8 and 3.7% annually. During this

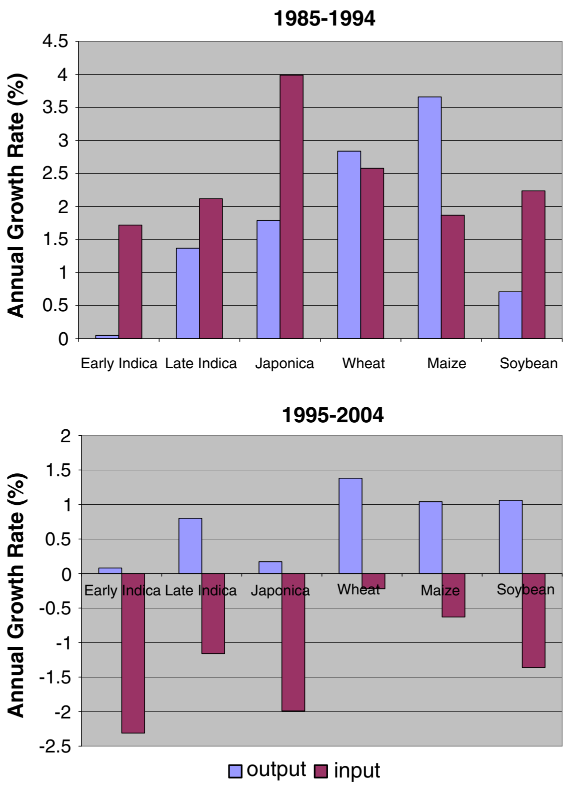

Fig. 1 Annual growth rate (%) of yield and total cost of main grain crops in China, 1985–2004. *Data source* National Agricultural Production Cost Survey (see Sect. 2 for complete description). See appendices for complete annual series of cost of production at national level. Growth rates generated by regression method

time inputs for these two crops rose, albeit at a slower rate (on average—for the three crops—about 2%).

While data are less available for crops beyond grain and soybeans before the mid-1990s, the record of output and input trends also is mixed (Tables 1, 2; columns 1 and 2). The seriousness of nearly uncontrollable outbreaks of cotton pests can be seen through the fall of output (−0.49% annually) and sharp rises in inputs (more than 4%, mostly for labor and materials for pest control). The growth rate of input used in hog production also rose faster than output. Therefore, the concerns that the output to input mix in agriculture extended beyond traditional stable crops at least had some basis. The case of beef, however, shows that output was still rising much faster than inputs in other sectors.

5.1 TFP performance before 1995

Total factor productivity analysis demonstrates that, while the concern for low TFP growth in China during the 1985–1994 decade is real, reliance on output and input trends can sometimes be somewhat misleading (Fig. 2, top panel). Perhaps due to smoothing across years (the output and

Table 1 Annual growth rate (%) of yield and total cost of cash crops (cotton and horticultural crops) in China, 1985–2004

Crop	1985–1994		1995–2004	
	Output	Total cost	Output	Total cost
Cotton	−0.49	4.60	2.68	−1.90
Horticultural crops				
Capsicum	NA	NA	2.87	2.22
Eggplant	NA	NA	1.47	2.90
Field cucumber	NA	NA	−0.40	−1.79
Field tomato	NA	NA	1.36	1.94
Greenhouse cucumber	NA	NA	1.11	0.60
Greenhouse tomato	NA	NA	2.95	1.50
Mandarin orange	NA	NA	1.30	0.13
Orange	NA	NA	−1.77	0.30

Data source National Agricultural Production Cost Survey (see Sect. 2 for complete description). See appendices for complete annual series of cost of production at national level

Growth rates generated by regression method

input growth rates were generated by using linear trends in the input and output series) using our methodology for analyzing TFP, early and late indica rice and soybeans, in fact, show a modest rate of gain of TFP during the late 1980s and early 1990s (about 1.8% annually, on average). Wheat and maize are also positive (although the increase is small). In contrast, japonica rice registered a fall in TFP between 1985 and 1994 (−0.12% annually).

The sources of growth—which can also not be identified using descriptive statistics and trend analysis—also vary among the crops. Positive technological change accounted for almost all the TFP rises for early and late indica rice and contributed about half of the rise of maize TFP. In contrast, some or all of the modest rises in TFP for wheat, maize and soybeans can be accounted for by increased efficiencies. While we can not identify the exact reason why there was a measured rise in the efficiency of production, these rates of increase are consistent with the measurements of deBrauw et al. (2004) which shows that the gradual liberalization of China's grain markets after 1985 generated efficiency gains for producers.

The record is mixed for non-grain crops (Tables 3, 4). The fall in cotton TFP (Row 1, columns 1–3, Table 3) shows that China's cotton production sector was indeed in danger of becoming uncompetitive during the 1985–1994 decade (as described in Qiao et al. 2006). Although the research system helped stem the fall by producing some new conventional cotton varieties, the efficiency of production fell (likely due to the uncontrolled rise in the large volume of pesticides that appeared on the market to control the emergence of the cotton bollworm population that was becoming increasingly resistant to conventional

Table 2 Annual growth rate (%) of output and total cost of livestock and dairy production in China, 1985–2004

Commodities	1985–1994		Early or mid-1990s–2004	
	Output	Total cost	Output	Total cost
Backyard hog production	1.24	2.47	5.29	−5.12
Specialized hog production	3.80	5.53	5.54	−5.37
Commercial hog production	0.29	0.86	13.05	−4.60
Specialized egg production	NA	NA	1.95	−1.87
Commercial egg production	NA	NA	2.43	−0.57
Beef production	10.2	−1.29	9.30	−0.92
Specialized milk	NA	NA	2.02	3.21
Commercial milk	NA	NA	5.19	0.71

Data source National Agricultural Production Cost Survey (see Sect. 2 for complete description). See appendices for complete annual series of cost of production at national level

Growth rates generated by regression method

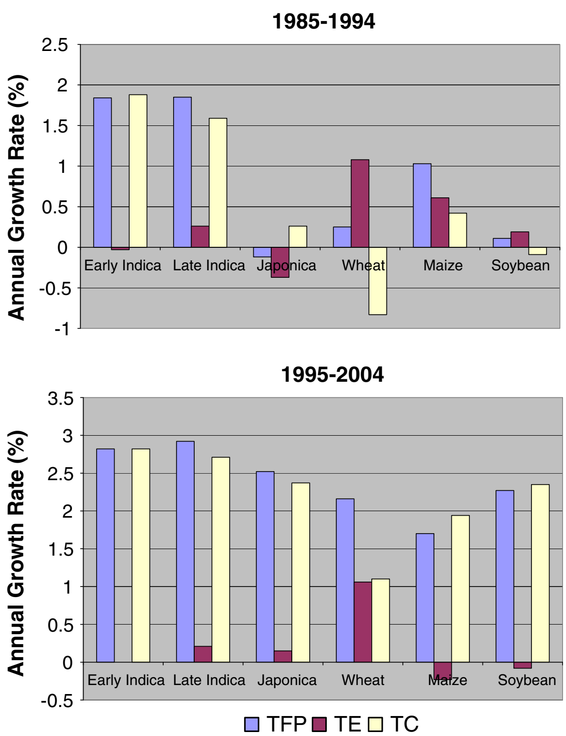

Fig. 2 Annual growth rate (%) of main grain crops' total factor productivity (TFP) and decomposition into technical efficiency (TE) and technical change (TC) in China, 1985–2004

pesticides). Some of the new pesticides, however, appear to not have been effective (meaning for a given level of input the output fell short of the production frontier—which by definition is measured as inefficiency). While the story of hog production TFP is largely the same (it is driven by rises in new technology), the importance of using our analytical approach is clear since it shows that TFP, in fact, rose between 1985 and 1994, unlike the story told by the raw output/input trends.

6 The record of TFP growth: 1995–2004

Our analysis of the period between 1985 and 1994 shows that the concerns of the world about the health of China's agricultural economy were not unfounded. There were some crops for which TFP growth was positive. However, for others TFP was falling or largely stagnant. Even optimists must have been sobered by the fact that on average TFP growth was below 2% per year (a rate often thought to be an indicator of a healthy agricultural sector). The fears of pessimists were further fueled by the deceleration of the growth of TFP. If the growth rates of the 1985–1994 decade were so much lower than the growth rates in the pre-1985 period, it was natural to be worried that the TFP rates of growth during the period after 1995 could even be lower. There also was such a lack of information on many of the rapidly emerging crops and agricultural commodities (e.g., horticultural crops and poultry and dairy) during the pre-1995 period due to the absence of data. The analysis in this section seeks to address these concerns.

6.1 Outputs and inputs after 1995

Unlike the decade before 1995, during the 10 year period between 1995 and 2004 output and input trends showed remarkable improvement and consistency (Fig. 1, bottom panel, and Tables 1, 2, columns 3 and 4). Of the 23 commodities for which we have complete output and input data during this period, in the case of 20 of them the rate of growth of outputs exceeds that of inputs. In particular, the rate of growth of output of all grains and soybeans outpace that of inputs.

Table 3 Annual growth (%) of cash crops' (cotton and horticultural crops) total factor productivity (TFP) and decomposition of TFP into technical efficiency (TE) and technical change (TC) in China, 1985–2004

	Growth rate (1980s–1990s)			Growth rate (1990/1991–2003)		
	TFP	TE	TC	TFP	TE	TC
Cotton	−0.34	−2.54	2.21	4.16	−3.47	7.63
Horticultural crops						
Capsicum	NA	NA	NA	1.86	−0.42	2.28
Eggplant	NA	NA	NA	2.24	−3.14	5.37
Field cucumber	NA	NA	NA	5.15	−1.27	6.42
Field tomato	NA	NA	NA	3.23	−0.50	3.73
Greenhouse cucumber	NA	NA	NA	5.86	0.62	5.24
Greenhouse tomato	NA	NA	NA	4.02	−2.43	6.45
Mandarin orange	NA	NA	NA	2.33	−2.19	4.52
Orange	NA	NA	NA	4.31	−3.20	7.50

Table 4 Annual growth (%) of livestock and dairy products' total factor productivity (TFP) and decomposition into technical efficiency (TE) and technical change (TC) in China, 1985–2004

Products	Growth rate (1980s–1990s)			Growth rate (1990/1991–2003)		
	TFP	TE	TC	TFP	TE	TC
Backyard hog production	4.80	1.26	3.54	3.72	1.01	2.72
Specialized hog production	5.58	−0.14	5.72	5.35	−0.72	6.07
Commercial hog production	5.67	0.09	5.58	4.40	−0.38	4.78
Specialized egg production	NA	NA	NA	3.78	0.32	3.46
Commercial egg production	NA	NA	NA	4.83	1.44	3.39
Beef production	NA	NA	NA	4.41	0.01	4.40
Specialized milk	NA	NA	NA	0.48	−6.09	6.58
Commercial milk	NA	NA	NA	1.31	−3.26	4.57

There are also positive signs of a healthy agriculture outside the conventional grain economy. The recovery of China's cotton industry is shown by the remarkable turn around in annual output (+2.68%) and input (−1.90%) trends. No doubt the widespread emergence of Bt cotton—which allowed farmers to dramatically reduce pesticide use (and labor for spraying) while increasing yields—is a large part of the story. In the case of livestock, except for the specialized milk sector (that is mostly made up of large commercial dairies), the annual rate of rise of output of all commodities is greater than that of inputs.

Only in the horticultural sector is the record more mixed. The growth rate of output of five of the horticultural crops (capsicum; field cucumbers; greenhouse cucumbers; greenhouse tomatoes; and mandarin oranges) exceeds the growth rate of inputs. However, the opposite is true for eggplant, field tomatoes and conventional oranges. The fact that growth rate is greater for greenhouse tomatoes, and other greenhouse vegetables, than for field tomatoes and vegetables might be due to the more efficient and commercial farmers adopting greenhouses.

6.2 TFP and its sources, 1995–2004

The TFP analysis after 1995 tells an even more positive story in general about the health of China's agriculture than the output and input trends and demonstrates a sharp resurgence when compared to the 1985–1994 decade (Fig. 2, bottom panel, and Tables 3, 4, columns 4–6). Using the stochastic production frontier methods (described above—and used in the previous section), the rate of TFP growth for all 23 commodities—including grains, soybean, cotton, horticultural crops and livestock commodities—were all positive. Moreover, with the exception of maize (1.10%), capsicum (1.86%), specialized milk producing households (0.48%) and commercial dairies (1.31%), the annual growth rate of all commodities were in excess of 2%. In fact, using the value of output as rough weights and aggregating across all of the included commodities, the overall annual TFP growth rate of China's agriculture between 1995 and 2004 exceed 3%. When averaged with the growth rates during the 1978–1984 period and 1985–1995 period, between 1978 and 2004, China's agricultural TFP growth rate is likely to have been in excess of 3% annually, a rate that is remarkable for any country for such an extended period of time (Jin et al. 2002).

6.2.1 Rising technical change

The results also are consistent between the 1980s/early 1990s and late 1990s/2000s with regards to the sources of growth; technical change is driving the rise in productivity and is the foundation of the health of China's economy. When examining the source of grain and soybean TFP change (Fig. 2, bottom panel), technical change accounts for nearly all the rise for all crops except wheat (which accounts for half of TFP; while efficiency accounts for the other half). This finding is consistent with the findings of Jin et al. (2002) that found during the pre-1995 period, all of the positive change in TFP between the early 1980s and mid-1990s could be attributed to technological change. While we can not identify the exact source of technical change, the findings are consistent with the findings reported in Jin et al. (2002) that the new varieties that China's breeders were producing in the nation's breeding program during the 1980s (which were shown to have greater yield potential, among other new traits) were making their way into the fields of farmers.

The rise of technical change-based TFP growth in cotton and horticultural crops after 1995 (Table 3, columns 4–6) not only shows the effectiveness of China's domestic breeding programs (especially in the case of Bt cotton from the Chinese Academy of Agricultural Sciences), it also suggests that opening China to the import of new varieties from outside of China is an effective way to improve technology and TFP. Because China's officials allowed foreign varieties of Bt cotton to be commercialized, farmers have benefited from having access to a productivity-increasing, foreign-produced technology (Huang et al. 2002).[3] Our interviews in the horticultural industry likewise suggest that the large share of the measured rise in TFP that is due to technical change is from new varieties that were allowed to be imported from abroad. Since the early 1990s, horticultural seed industry traders told us that they faced few barriers in importing horticultural seed from Europe, Japan or the United States. During our household interviews during two large household surveys of vegetable traders in 2005 and 2006 we found that more than half of the varieties of horticultural crops had names that were clearly foreign in origin. Farmers told us that the varieties were both higher yielding and produced higher quality fruits and vegetables.

Imported technology and rising research effort into livestock between 1995 and 2004 also is likely to be behind the rapid rise of technical change-based TFP in the livestock sector (Table 4, columns 4–6). During the 1990s China encouraged the importation of large amounts of new genetic material for the hog, beef, poultry and dairy industries. Discussions with officials—from both inside and outside of China—suggest that new hog varieties from the US and Japan; new beef and dairy cattle genetics from Canada, New Zealand and Australia; and poultry technology from around the world, including the US, have greatly increased the genetic quality of China's livestock industry. Apparently these new innovations have penetrated into China's villages and fledgling commercial sectors as technical change is shown to have risen sharply.

6.2.2 Falling efficiency

But while the results are consistent with the positive effect of rising access to new technologies and improved genetics, they also expose some serious weaknesses in China's agriculture. In the case of more than half of our study's commodities (14 of 23), TFP would have been higher had not producers become less efficient during the study period, 1995–2004. In the case of maize, soybean, cotton, seven of the eight horticultural crops (all but greenhouse cucumbers) and half of the livestock commodities (specialized and commercial hog producers; and specialized and commercial dairies), producers were less efficient in 2004 than they were in 1995.

While the analysis can not identify the precise source of the fall in efficiency, we believe that there are two sources—one that may not be addressable by policy; the other which may be. It is interesting to note that perhaps with the exception of soybeans, all of the crops that have suffered falls in efficiency are those that have experienced rapid expansion since 1995. Maize, almost all horticultural crops and the specialized and commercial segments of the livestock industries have all grown much faster than the gross value of agricultural output in general; in other words, their share in the economy is expanding. Therefore, one perhaps unavoidable source of rising inefficiency is due to the expected disequilibrium that accompanies the rapid expansion of any crop (or other industrial product). New producers are adopting new crops and they require time to learn how to produce the crop and market it effectively. As expansion occurs for crops, often times the new cultivated area is displacing cultivated area of other crops and the new area may be relatively less favorable. This would, of course, lead to a fall in the measured efficiency of the

[3] As we explain in Huang et al. (2002), Bt cotton varieties are being created and commercialized by both foreign companies and China's own domestic company, an enterprise with ties to the Chinese Academy of Agricultural Sciences.

sector. Hence, some of this fall is perhaps unavoidable and will continue as long as the share of the crop is expanding.

However, it is likely that another part of the fall in efficiency that is avoidable is occurring due to the deterioration of the extension system. As discussed above, China's extension system has steadily eroded during the reform era, and a part of this has occurred after 1995. Especially given three factors—the nature of China's farming sector (which is almost all made up of extremely small farms (CNBS 2005); the absence of cooperation (Shen et al. 2006); and the rapid rise of technology (which, as discussed immediately above, is responsible for the rise in China's TFP)—the nation needs a strong extension system. Yet, at the very time extension services are needed, they are disappearing. Therefore, it is perhaps unsurprising that in 14 of the 23 commodities production is becoming more inefficient and in all of the rest the contribution of efficiency is zero or far below the contribution of technical change.

7 Conclusions

Our findings in this paper about the record of TFP growth in China are remarkably consistent—especially after 1995 (the main focus of our paper). Our analysis shows that China's agricultural TFP has grown at a healthy rate for all 23 commodities. TFP growth for the staple commodities generally rose around 2% annually; TFP growth for most horticulture and livestock commodities was even higher (between 3 and 5%). This rise in TFP is high by both historic and international standards and demonstrates the healthiness of China's economy.

Equally consistent, we find that most of the change is accounted for by technical change. The analysis is consistent with the conclusion that new technologies have pushed out the production functions, since technical change accounts for most of the rise in TFP. In the case of many of the commodities, however, the efficiency of producers—that is, the average distance of producers from the production frontier—has fallen. In other words, China's TFP growth would have been even higher had the efficiency of production not eroded the gains of technical change.

Although we do not pinpoint the source of rising inefficiency, the results are consistent with a story that there is considerable disequilibrium in the farm economy during this period of rapid structural change. Hence, our paper, more than anything, establishes a basis for China's (and international) leaders and policy makers who are committed to keeping a strong agricultural supply capacity to confidently invest in the nation's agricultural research system and to open up trade channels to allow for the importation of new technologies. The basis for doing so primarily rest on the importance that technology and the institutions that create, import and spread it has had on TFP in the past. TFP has continued to rise after 1995 primarily due to past contributions of technology.

However, our analysis also identified a possible weakness in China's agriculture. Although part of the measured fall in efficiency in many of the crops may be due to the disequilibrium that may naturally occur during the expansion phase of a crop, it also is clear that farmers are getting little help in making these adjustments from the extension system. If anything (due to the rise in importance of new technology), it is a time that China's extension system should be built up. Many factors—fiscal; administrative; etc.—are behind the deterioration of China's extension system. One of the biggest challenges for China's officials, of course, is to combat this fall. If they can do this, recapturing the recent fall in efficiency it could be another source of productivity rise in the coming years.

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Appendix 1: Details on the data used for the livestock TFP analysis

An ongoing problem for the study of livestock productivity in China is obtaining accurate data. The majority of studies of Chinese agricultural productivity have used data published in China's statistical yearbook. While this source disaggregates gross value of agricultural output into crops, animal husbandry, forestry, fishing and sideline activities, input use is not disaggregated by sector. A major improvement we introduce is to utilize additional data collected at the farm level that will allow the construction of time-series of input use by the livestock farm type. A further problem with livestock data from the statistical yearbooks is the apparent over-reporting of both livestock product output and livestock numbers (Fuller, Hayes and Smith, ERS). This problem also needs to be addressed if the possibility of biased livestock productivity estimates is to be avoided.

We specify four inputs to livestock production—breeding animal inventories, labor, feed and non-livestock capital. We describe below the construction of data series for these livestock production inputs, as well as our approach to overcoming the over-reporting of animal numbers and outputs.

Livestock commodity outputs

Concerns over the accuracy of official published livestock data include an increasing discrepancy over time between supply and consumption figures and a lack of consistency between livestock output data and that on feed availability. Ma et al. (2004a, b—henceforth MHR) have provided adjusted series for livestock production (and consumption) that are internally consistent by recognizing that the published data do contain valid, albeit somewhat distorted information. In order to adjust the published series, new information from several sources is introduced. Specifically, MHR use the 1997 national census of agriculture as a baseline to provide an accurate estimate of the size of China's livestock economy in at least one time period. The census is assumed to provide the most accurate measure of the livestock economy since it covers all rural households and non-household agricultural enterprises. The census also collected information on the number of slaughterings (by type) during the 1996 calendar year. A second source of additional information is the official annual survey of rural household income and expenditure (HIES) that is run by the China National Bureau of Statistics (CNBS). Information collected in that survey includes the number of livestock slaughtered and the quantity of meat produced for swine, poultry, beef cattle, sheep and goats, and eggs. MHR assumes the production data as published in the statistical yearbook to be accurate from 1980 to 1986. Beyond this date, that data are adjusted to both reflect the annual variation as found in the HIES data and to agree with the Census data for 1996. Further details of the adjustment procedure can be found in MHR. The adjusted series includes provincial data on livestock production, inventories and slaughterings.

Animals as capital inputs

Following Jarvis we recognize the inventory of breeding animals as a major capital input to livestock production. Thus opening inventories of sows, milking cows, laying hens and female yellow cattle are used as capital inputs in the production functions for pork, milk, eggs and beef, respectively. Provincial inventory data for sows, milking cows and female yellow cattle are taken from official sources and adjusted for possible over-reporting as described above.

Additional problems exist with poultry inventories. China's yearbooks and other statistical publications contain poultry inventories aggregated over both layers and broilers. No official statistical sources publish separate data for layers. Ma et al. (2004a, b), however, provide adjusted data on egg production, and the State Development Planning Commission's agricultural commodity cost and return survey provided estimates of egg yields per hundred birds. Thus layer inventories, at both the national and provincial levels, are calculated by dividing output by yield.[4] A simple test shows that the sum across provinces of our provincial layer inventories is close to our estimate of the national layer inventory in each year.[5]

Feed, labor and non-livestock capital inputs

Provincial data for these production inputs are obtained directly from the Agricultural Commodity Cost and Return Survey.[6] Thought to be the most comprehensive source of information for agricultural production in China, the data have been used in many other studies (e.g., Huang and Rozelle 1996; Jin et al. 2002). Within each province a three-stage random sampling procedure is used to select sample counties, villages and finally individual production units. Samples are stratified by income levels at each stage. The cost and return data collected from individual farms (including traditional backyard households, specialized households, state- and collective-owned farms and other larger commercial operations) are aggregated to the provincial and national level datasets that are published by the State Development Planning Commission.

The survey provides detailed cost items for all major animal commodities, including those covered in this paper. These data included labor inputs (days), feed consumption (grain equivalent) and fixed asset depreciation on a 'per animal unit' basis. We deflate the depreciation data using a fixed asset price index. We calculate total feed, labor and non-livestock capital inputs by multiplying the input per animal by animal numbers. For the latter, we use our slaughter numbers for hogs and beef cattle, and the opening inventories for milking cows and layers since these are the 'animal units' used in the cost survey. It is clear that this procedure, necessitated by the available data, excludes some input usage, such as that by other animal categories within the pig and cattle herds.

Livestock production structures

China's livestock sector is experiencing a rapid evolution in production structure, with potentially large performance differences across farm types. For example, traditional

[4] The cost and return survey did not contain egg yields for every province for each of the past 15 years. Provincial trend regressions were used to estimate yields in such cases.

[5] Data on inventories of breeding broilers are available only from 1998, and we could not discover any way of deriving earlier data from the available poultry statistics. This severely limited our ability to analyze productivity developments in this sector.

[6] This survey is conducted through a joint effort of the State Development Planning Commission, the State Economic and Trade Commission, the Ministry of Agriculture, the State Forestry Administration, the State Light Industry Administration, the State Tobacco Administration and the State Supply and Marketing Incorporation.

backyard producers utilize readily available low-cost feedstuffs, while specialized households and commercial enterprises feed more grain and protein meal. The trend from traditional backyard to specialized household and commercial enterprises in livestock production systems therefore implies an increasing demand for grain feed (Fuller et al. 2002). To estimate productivity growth by farm type, our data must be disaggregated to that level. This is not a problem for the feed, labor and non-livestock capital variables, since they are recorded by production structure in the cost surveys. However, complete data series on livestock output and animal inventories by farm type do not exist.

Our approach to generating output data by farm type is to first construct provincial 'share sheets' that contained time series data on the share of animal inventories (dairy cows and layers) and slaughterings (hogs) by each farm category (backyard, specialized and commercial).[7] Inventories of sows by farm type are then generated by multiplying the aggregate totals (see earlier section) by the relevant farm-type hog slaughter share. We note that this assumes a constant slaughterings-to-inventory share across farm types for hog production, and therefore assumes away a possible cause of productivity differences in this dimension across farm types. However, it proved impossible to gather further data to address this concern.

To disaggregate our adjusted livestock output data by farm type, it is important to take into account yield differences across production structures. From the cost surveys we obtained provincial time-series data on average production levels per animal (eggs per layer, milk per cow and mean slaughter liveweights for hogs). Such information is then combined with the farm-type data on cow and layer inventories and hog slaughterings to produce total output estimates by farm type that were subject to further adjustment so as to be consistent with the aggregate adjusted output data.

Information that allows us to estimate the inventory and slaughter shares by farm type and by province over time comes from a wide variety of sources. These include the 1997 China Agricultural Census, China's Livestock Statistics, a range of published materials (such as annual reports, authority speeches and specific livestock surveys) from various published sources, and provincial statistical websites. The census publications provide an accurate picture of the livestock production structure in 1996 (Somwaru et al. 2003). However, the census defines just two types of livestock farms—rural households and agricultural enterprises (including state- and collective-owned farms). We interpret the latter as 'commercial' units, but additional information is used to disaggregate the rural households into backyard and specialized units. Agricultural statistical yearbooks and China's Livestock Statistics provide data on livestock production structure during the early 1980s, when backyard production and state farms were prevalent. These sources, plus the Animal Husbandry Yearbooks and provincial statistical websites also provide estimates of livestock shares for various livestock types, provinces and years. When all these data are combined with 1996 values from the census, many missing values still existed. On the assumption that declining backyard production and increasing shares of specialized and commercial operations are gradual processes that evolved over the study period, linear interpolations are made to estimate a number of missing values.

[7] We did not disaggregate beef data by farm type, since the cost survey presented beef information for just a single category—rural households.

Appendix 2: Details on the data used for the dairy sector TFP analysis

Since dairy sector official statistics face the same over-reporting problem as described in "Appendix 1" and the data adjustments for dairy sector were not included in Ma et al. (2004a, b), we have to adjust data on milk output and dairy cattle inventories before estimating dairy sector TFP. To maintain the consistency with the livestock commodities, we use a similar approach to adjust milk output and the dairy cattle numbers. In order to adjust the published series, new information from several sources is introduced.

First, the 1997 national census of agriculture is used as a baseline to provide an accurate estimate of the size of China's dairy sector economy in at least one time period. As described in Ma et al. (2004a, b), the census is assumed to provide the most accurate measure of dairy cattle inventory in 1996 since it covers all rural households and non-household agricultural enterprises.

Second, we also used the official annual survey of rural household income and expenditure (HIES) that is run by the China National Bureau of Statistics (CNBS). Information collected in that survey includes the numbers of cow milk output.

We also assume that the dairy cattle numbers and milk output data as published in the statistical yearbook are accurate from 1980 to 1986. Beyond this date, we assume that the data are adjusted to both reflect the annual variation as found in the HIES data and to agree with the Census data for 1996.

The adjustment procedure for dairy sector production data is the same as described in Ma et al. (2004a, b). The adjusted series includes provincial data on dairy cattle inventory and milk output.

Appendix 3

See Table 5.

Table 5 The information on sample size

Commodity	Time periods covered	Min no. of provinces per year	Max no. of provinces per year	Total observations
Hogs				
Backyard households	1980–2001	15	27	491
Specialised households	1980–2001	3	25	285
Commercial	1980–2001	2	25	224
Layers				
Specialised households	1991–2001	10	22	160
Commercial	1991–2001	8	16	132
Beef				
Rural households	1989–2001	4	10	97
Milk				
Specialised households	1992–2001	5	16	91
Commercial	1992–2001	10	23	155
Crops				
Corn	1985–2004	19	22	418
Wheat	1985–2004	21	25	459
Early rice	1985–2004	7	11	179
Late rice	1985–2004	4	9	155
Japonic	1985–2004	14	17	313
Soybean	1985–2004	13	18	302
Cotton	1985–2004	14	17	308
Horticulture				
Capsicum	1990–2003	6	28	260
Eggplant	1990–2003	12	28	306
Field cucumber	1990–2003	10	26	266
Field tomato	1990–2003	9	25	259
Greenhouse cucumber	1990–2003	6	21	186
Greenhouse tomato	1990–2003	5	20	193
Mandarin orange	1990–2003	2	6	118
Orange	1990–2003	3	11	160

Vegetables cover only urban areas of provincial capital cities

Appendix 4

See Table 6.

Table 6 Contribution of individual crops to total agricultural GDP (5 year average)

Year	1980–1984	1985–1989	1990–1994	1995–1999	2000–2005
Rice (%)	20.7	20.4	16.9	15.1	9.4
Wheat (%)	12.7	11.5	9.1	8.8	4.8
Maize (%)	7.9	7.0	6.8	7.3	5.3
Soybean (%)	3.1	2.9	2.5	2.0	1.5
Cotton (%)	6.0	4.1	4.4	3.1	2.4
Pork (%)	10.9	16.2	17.5	19.5	17.6
Milk (%)	0.7	0.8	0.7	0.7	1.3

Table 6 continued

Year	1980–1984	1985–1989	1990–1994	1995–1999	2000–2005
Poultry (%)	2.7	2.7	4.2	6.0	5.7
Fruit (%)	1.6	3.5	3.9	3.4	3.5
Vegetable (%)	10.3	13.2	14.3	10.6	10.8
Sugar (%)	1.0	1.4	1.4	1.0	0.8
Sub-total (all the above) (%)	77.7	83.7	81.5	77.4	63.1
Residual (%)[a]	22.3	16.3	18.5	22.6	36.9

[a] Residual includes forestry, fishery and all the other agricultural related activities

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